DEVELOPING THE DATA BASE

A FRAMEWORK FOR MONITORING THE PHYSICAL ECONOMY

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Abstract

The size and complexity of global material flows have increased significantly in recent decades. Various strategies have been developed to improve analysis of global material flows, but we are still a long way from a sufficiently consistent and robust understanding of the global physical economy. Hence, the MinFuture[1] project is based on the hypothesis that a robust map of the global physical economy is needed in order to address these challenges. The project approaches this by developing a methodological framework for the monitoring of the physical economy. The framework proposed is based on Material Flow Analysis (MFA), a tool widely used for tracking materials and energy in the economy. MinFuture introduces a pyramid with seven components (systems, data, uncertainty, models and scenarios, visualisation, indicators, and strategy support) to illustrate key requirements for monitoring the economy's physical flows and stocks of materials. The system forms the foundation of any given MFA; it represents the coordinate system of the physical economy being examined. Without this coordinate system, the measurements providing data cannot accurately be assigned to flows or stocks and a robust interpretation of data and system will not be feasible. The main conclusion of the MinFuture project is that data generation and interpretation has to be anchored in solid system understanding and description.

Introduction

The complexity of global material flows have increased drastically over in recent decades as a consequence of population growth, urbanization, globalization, technological development and sophistication in supply chain management. The increased use of materials has been accompanied by increased energy use and growing waste and emission generation along the supply chain. This transformation of the physical economy has resulted in growing concerns over the secure supply of raw materials and the overall sustainability of the economic system. The EU funded MinFuture[1] project is based on the hypothesis that a robust map of the global physical economy is needed in order to address these challenges. Data are collected from a variety of sources, including national statistical offices, international trade statistics, geological surveys, trade associations and industry. Assumptions are often needed to fill in gaps in data and therefore various ongoing activities are aiming to establish a harmonised database. For example, Myers et al. (2018) presents the Unified Materials Information System (UMIS) to enable material stocks and flows data to be comprehensively integrated across space, time, materials, and data type independent of their disaggregation.

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This brief summary based on MinFuture deliverable 5.1 (Petavratzi et al. 2018) presents a methodological framework for monitoring the physical economy that can effectively and systematically respond to the aforementioned concerns and support the development of strategies to address them. The following describes such a framework, including a short analysis of its components, and provides guidelines to assist its implementation, focusing on the development of a database.

Increasing complexity of problems

Raw materials are the backbone of the value chain of industrial production, playing a prominent role as a source of prosperity, growth and competitiveness in Europe. By contributing to employment and value generation, the secure supply of mineral resources is crucial for the European Union's growth and stability. The global use of mineral raw materials has increased exponentially over the past few decades, both in overall quantity and in number and combination of minerals and elements used for different applications.

The European Commission (EC) has taken a variety of actions to address these challenges, including climate and circular economy action plans. To ensure a sustainable supply of raw materials, the EC has launched two interlinked actions: the Raw Materials Initiative (RMI) and the European Innovation Partnership on Raw Materials (EIP-RM), which has developed a Strategic Implementation Plan (SIP) with 95 actions to foster innovative solutions (European Commission 2008, 2013). All of these policies aim at controlling the complex system of material and energy flows of the economy, which we call socioeconomic metabolism or, simply, the physical economy.

Existing monitoring frameworks are insufficient

Currently, there are no monitoring programs for the physical economy. Traditionally, several government agencies monitor different aspects of the physical economy, such as geological surveys measuring mineral reserves and mine production flows. However, current measurements of material (and energy) stocks and flows are insufficient to address the challenges outlined above for several reasons:

- *Lack of a system perspective:* The current monitoring programs measure isolated stocks and flows, but neglect to show their connections. The lack of a system perspective makes it difficult for government agencies and industry to make use of the data for addressing more complex problems related to the entire supply chains.
- *Incomplete measurements:* Current monitoring programs include large gaps of stocks and flows that are not measured. Due to the lack of a systems perspective, these gaps may not be recognized by policy makers or industry.
- *Fragmentation of data and harmonization needs:* Government agencies in different countries and regions often use different reference points for their measurements. This results in difficulties for comparing data of different countries or for developing aggregate level information, for example on European or global scales. Data fragmentation is a major issue for organisations, such as geological surveys or statistics offices, who collect data from multiple sources and put substantial effort into standardisation and harmonisation. However, there also exist problems using different datasets, for example production and trade data that are not inherently compatible.

Need for system-based monitoring

System-based monitoring of the physical economy is needed in order to effectively inform government policies, industry strategies as well as future measurements programs. It helps to

- interpret the existing physical data,
- provide information and link different data points (add information to the existing data),
- allow for consistent mass balance accounting,
- facilitate data harmonization,
- make the existing data more robust and
- allow for model and scenario development.

In the following, the proposed framework is described in more detail. It includes a short analysis of its components and provides guidelines to assist its implementation, focusing on the development of a database. This document represents a summary and start of a 'journey' to monitor the physical economy.

Framework for monitoring the physical economy

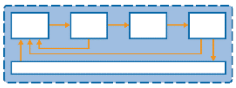
Material flow analysis (MFA) is the method used to track the physical economy, namely the stocks and flows of material and energy in a system defined in space and time (Brunner and Rechberger 2016). The outcomes of MFA can be used to inform strategies for resource management and emissions control. MFA has experienced considerable development over the past three decades. A large and still growing community is using this method to analyse the anthropogenic metabolism (Rechberger et al. 2014). MFAs incorporate databases of increasing size and quality and reveal more and more details about material flows into, within and out of given systems. As a consequence, MFAs are of increasing size and system structures are of increasing complexity (Schwab 2016).

The purpose of the MinFuture framework is not to provide a step-by-step guide to developing MFA. Instead, it aims to deliver clarity on the essential components needed for monitoring the physical economy. More detailed examples and analyses on specific challenges can be found in the deliverable reports of the MinFuture project[2]. The framework for monitoring the physical economy is based on four dimensions and the pyramid with its seven components.

The four dimensions of MinFuture

The methodology builds on and integrates four core dimensions: *stages, trade, layers, time*

1. *Dimension Stages*

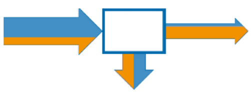


The dimension 'stages' represents the various transformation and use stages of materials across their lifetime. The stages can be specific to a material under investigation (e.g. beneficiation stages of crushed rock), but commonly materials are tracked across the whole life cycle, from extraction through to refining and manufacturing, to use and eventually to disposal and recycling. Material cycles can be developed with different levels of aggregation representing the supply chain and are governed by the scope of the study. For example, depending on the aim of the study, the stages dimension might not need to be at a highly disaggregated level (e.g. Harper et al. (2011)) or there will be need to provide a higher resolution (e.g. Liu and Müller (2013a)).

2. *Dimension Trade*

The 'trade' dimension is central for tracking the transport pathways and changes of ownership of goods as they flow through the global economy. The EU, along with other developed countries, depends on the supply of raw materials from international markets. Understanding and visualising the global nature of raw materials value chains to ensure a sustainable supply of primary and secondary raw materials for the EU requires a good understanding of how EU material cycles are linked to other regions/countries by international trade. The trade dimension is linked to the stages dimension in which the stages of a material cycle can occur in different countries; this is exemplified in Liu and Müller (2013b).

3. *Dimension Layers*



The 'layers' dimension explores the interactions and changing characteristics of materials across their life cycle. It aims to integrate aspects such as total mass, compositional variation, energy content, and monetary value into product flow models. In addition, materials do not exist in isolation in products, so developing maps where the interlinkages between materials and products are identified can form an additional layer to the mass balance model.

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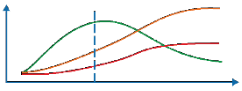
[2] *https://minfuture.eu/*

4. Dimension Time



The ‘time’ dimension provides the basis for model calibration and future scenario modelling. The analysis of historical material flows and their relationship to population dynamics is a key factor for determining system responses and parameter sensitivity for future scenarios. For example, dynamic MFA for aluminium stocks and flows are available at different levels (Buchner et al. 2015; Løvik et al. 2014; World Aluminium 2018). Understanding the dynamics of demand-supply interdependencies and relating these to, for instance, the planning process for new mining activities (time from exploration to mining often exceeds 10 years) is a key decision-making element for supply chain planning.

The pyramid with its seven components

The MinFuture pyramid, which is composed of the seven component systems - data, uncertainty, models and scenarios, visualisation, indicators, and strategy support - describes essential MFA elements required for monitoring physical flows and stocks of materials (see Figure 1). The components are organised in a hierarchical order as the robustness of higher levels depends on the robustness of the lower level(s). Combining these components adds new information and robustness and supports the development of material strategies.

Figure 1: The MinFuture Pyramid comprises the physical economy monitoring framework

System represents the totality of the stocks and flows within boundaries defined in space and time at a chosen level of (dis-)aggregation. It includes observed and unobserved stocks and flows. Adding a system definition to observed data adds information: A system defines the context of observed flows and it allows for calculation of unobserved flows using mass balance.

Data form the foundation of MFAs. They represent observations of either stocks (at a given point in time) or flows (over a given time period).

Models in this context are mathematical representations of material cycles. They reflect the system definition and the drivers of cycles such as population growth or technologies used. They are used to simulate MFA-based trends and developments. *Scenarios* are assumptions of plausible future cycles that are consistent with the mass balance principles and the assumed drivers. They can be used to make forecasts or to evaluate the effectiveness of alternative strategies.

Uncertainty is inherent in all MFAs of historical or future cycles due to errors in system definitions and the data used. Approaches to uncertainty analysis aim at making uncertainties transparent and reducing them. They enable the modeller to make assumptions that are more robust and become aware of the model's strengths and limitations.

Indicators stands for quantitative measures that aim to reflect the status of complex systems. They are used to analyse and compare performance of businesses, sectors or economies across countries, and to determine policy priorities.

Visualisations are different maps of complex systems. They can inform decision making in industry and government by visualizing status and historical trends as well as potential future developments under different conditions. Visualization tools are developed to support the recording (monitoring), exploration (analysis) and explanation (interpretation) of information.

Strategy support has two aspects: (1) Supporting political strategies for raw materials that aim at reaching different goals, such as those of the Strategic Implementation Plan (SIP) of the European Innovation Partnership on Raw Materials, the Circular Economy Action Plan or the SDGs. (2) Supporting strategies for improving and expanding the use of MFA in academia, governments and industry. (1) is addressed through undertaking case studies on material use in low-carbon technologies. (2) is addressed through developing a roadmap.

Key monitoring principles for developing a database

The key monitoring principles aim to assist practitioners in making informed decisions when conducting MFAs of any given material. They represent guidelines rather than means of determining what is right or wrong in an MFA. They aim to provide recommendations on how to conduct MFAs or to bring attention to issues that MFA practitioners should be attentive. The following key monitoring principles focus on the development of a database and concentrate on the system and data components.

System

Systems define where materials are located, either in the form of stocks or in processes, but also where they are moving to (flows). Mathematically, systems are defined through (mass or energy) balance equations, which include observed and unobserved flows (e.g. material dissipation). Furthermore, systems can be defined using different levels of aggregation, which is determined by the objectives of an investigation. Strong system definitions reflect the real system adequately at an aggregation level that serves the purpose of their models. Without good system understanding, the MFA will be of poor quality and may even lead to wrong conclusions. Spending adequate time to understand the real system and how best to reflect it in MFA is therefore very important. The development of systems requires substantial background research as well as engagement with multiple stakeholders and industry to ensure that the MFA model aligns well with the real one.

Ultimately, the system represents a map of the processes, material stocks and flows in a supply chain and forms the foundation of any given MFA; they represent the coordinate system of the physical economy being examined. Without a coordinate system, the measurements provided by data cannot accurately be placed to flows or stocks. The examples below aim to illustrate how systems can be developed in order to provide better coordinate systems for some known challenges. Systems are very much linked to data and without proper systems in which the data can be placed, robust interpretation can become challenging. Below, two examples illustrate challenges related to the system definition.

Example 1: Crude ore versus beneficiated ore

Some geological surveys report the crude ore in their statistics, whilst the majority report the beneficiated ore, namely the valuable part of the ore. The difference between the two represents the waste rock, Figure 2. Let us assume now that the aim of a study is to understand global production of a mineral commodity. When compiling data from different sources which report at different points in the system and which do not provide sufficient metadata information on, for example, the metal content of the crude ore, then it is highly likely that errors will be introduced during the calculation process.

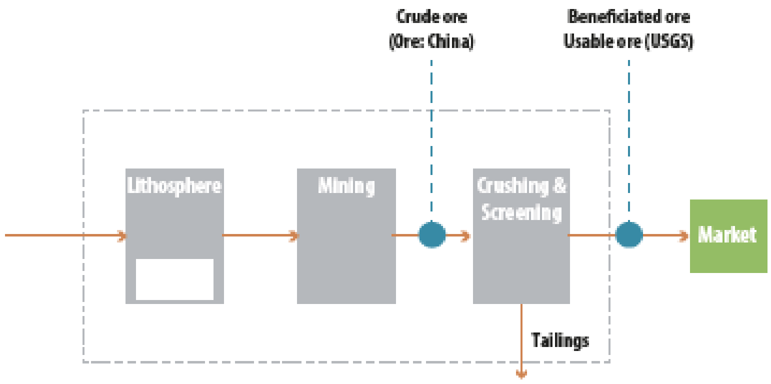


Figure 2: An illustration of the measurement points for crude and beneficiated ore

Example 2: Production versus sold production

Most statistical agencies and geological surveys report data on production, sold production, or shipment, Figure 3. However, these terms represent different parts of the value chain. Production is the quantity of a material produced directly from a mine in a given year. Shipment and sold production represent the quantity of a material that has been sold in a given year. Often companies have inventories where material is stored after production. Sold production or shipmen may represent a quantity of a material that originates from an inventory. Therefore, the terms production and sold production or shipment do not mean the same thing and should not be used interchangeably as they may introduce errors to MFA. Equally, data providers should try to remove any inconsistencies associated with these terms by providing additional information on the measurement point they represent

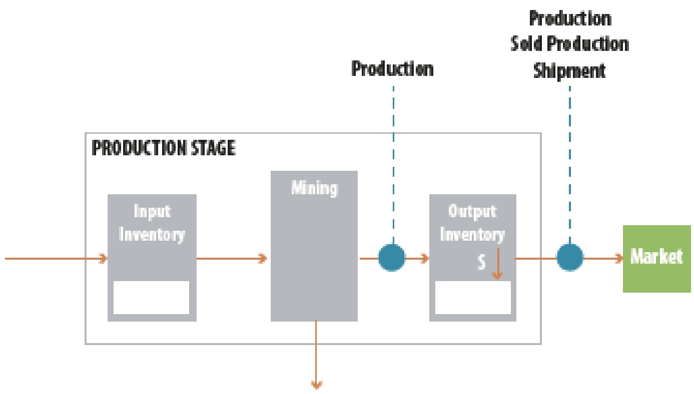


Figure 3: An illustration of the measurement points for production and production sold / shipment

Data

Data represent observations of either stocks (at a given point in time) or flows (over a given time period). Enabling an efficient monitoring of the physical economy is a data intensive task and requires data along the entire supply chain and across regions and nations. However, currently the data needed for compiling material cycles are often fragmented, inconsistent and not harmonized.

Current data collection is done by several governmental agencies for a variety of purposes. This often leads to different reference points for the measurement and further leads to difficulties in compiling data from several nations and institutions. Data used in MFA are collected from a variety of sources, including national statistical offices, international trade statistics databases, data from geological surveys, trade associations and industry. The data is also not reported within a system context and for this reason individual MFA practitioners need to gather data from a variety of sources, interpret the data and place them to the best of their abilities within a system. The implications of this are ambiguous datasets that cannot represent the real system well and cannot be used to their full potential in MFA without introducing assumptions about their definition. This often leads, as a result, to false interpretations of data.

To be able to monitor the physical economy in a consistent matter, data needs to be collected and provided with a system context in mind. Reporting data within a systems context adds information and increases the robustness as it provides coordinates to the measurement. In the figures shown in the section on systems above, the reference points are mapped within a system, which reduces the potential for miscommunication. It further allows for an increased level of transparency. By mapping reference points within a system, both what we know as well as our knowledge gaps are made explicit.

Summary and Conclusion

Growing global raw materials and energy consumption, accompanied by increasing waste production and emissions, is leading to growing concern over the sustainability and security of supply. Understanding the physical economy is highly relevant for supporting the development of strategies to address challenges like the increasing complexity of problems, the insufficiency of existing monitoring frameworks, and the establishment of system-based monitoring. Although several attempts have been undertaken to integrate data from various sources so as to provide a systematic overview, many initiatives are based on data that are: (i) highly fragmented, (ii) inconsistent, (iii) measured but not available due to confidentiality reasons, or (iv) not measured at all and need to be estimated, often on weak grounds resulting in large degrees of uncertainty. To address these challenges, a methodological framework for the monitoring the physical economy has been developed.

Key summary points:

- System-based monitoring of the physical economy is essential to effectively inform government policies, industry strategies as well as future measurements programs.
- Disconnected and non-harmonised data, often describing single flows of materials, exist from a variety of sources, but they are not used in a system context and it is therefore impossible at present to monitor material cycles from cradle to cradle.
- Monitoring of the physical economy is vital, but there are several challenges to overcome - starting with the development and subsequent broad application of a framework that facilitates its systematic development.

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